



## Machinery Messages

### Two case histories

# Advancement of Turbine Supervisory Instrumentation continues to help solve machinery problems

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**T**he use of on-line computer systems for vibration data collection and machinery diagnostics has become increasingly common during recent years. On-line monitoring systems can rapidly provide information on the mechanical condition of machinery in easy-to-interpret formats. Such monitoring systems eliminate tedious, time-consuming, hand logging of data and the need for strip chart recorders. Accurate records are essential for predictive maintenance programs. Automatic capture and storage of data, which might otherwise be lost, can drastically reduce the need to call plant engineers, technicians and maintenance personnel. Stored data can be reviewed and analyzed when convenient, or sent on disk to be reviewed by consultants.

Vibration characteristics of a machine, can and will, be greatly affected by process changes and other factors external to a machine train. Comparison of changes in machine dynamic behavior, and in process-related variables, can provide valuable insight on operational conditions. Knowledge of these changes, and how they relate to one another, can provide information on what process condition could be changed to minimize vibration or what process condition should be avoided altogether.

Machines of the same make and model may demonstrate varying degrees of behavioral similarity. However, all machin-



Sierra Pacific Power Company's Valmy Station in Northern Nevada USA maintains and operates two turbogenerator sets.

ery will demonstrate some unique operating characteristics. Machine response can be significantly affected by a variety of parameters including bearing and seal clearances, alignment, support stiffness, and thermal/load effects. Therefore, characterization of a machine must begin by generating a behavioral knowledge base over the range of actual operating conditions. Computerized monitoring systems make this possible.

The identification of machine characteristics in an actual service environment has been restricted primarily to times when diagnostic services are required. In such cases, management is focused primarily on solving the problem at hand rather than increasing its machinery knowledge base. This is

quite understandable, as significant economic ramifications are usually associated with machinery whose performance is compromised, or worse yet, which poses a potential safety hazard. Ideally, operations personnel could become familiar enough with a machine's characteristic behavior that unplanned maintenance could be eliminated.

A clear understanding of machine behavior can only be achieved through an accurate picture of rotor dynamic performance characteristics. Achieving this goal often presents many challenges. Availability of transducer placement locations along a machine train, and the types of transducers being used, are frequently limiting factors. It may be physically difficult to mount transducers in desired locations, or the selected mounting location can limit access and serviceability. Environmental conditions will be a controlling factor as well. The cost of transducer installation is also important. The high reliability of currently available transducers greatly reduces servicing requirements and, therefore,

the need to provide easy access. If machine trains have few transducers, it is difficult to characterize rotor behavior accurately, as the information from each transducer is applicable only to the specific point of observation and operating conditions during measurement.

A more accurate measure of machine condition can be obtained through the placement of multiple transducers. In addition, diagnostic capabilities are enhanced. Microcomputers are designed to store and handle large amounts of information. In fact, the application of a computer is essential in order to store, trend and analyze the vast amount of data being captured.

This technique has been applied during required maintenance procedures at Sierra Pacific Power Company's (SPPC) Valmy steam power plant in Northern Nevada. Although operated solely by Sierra Pacific Power, this facility is jointly owned with Idaho Power. ►

## Case History #1

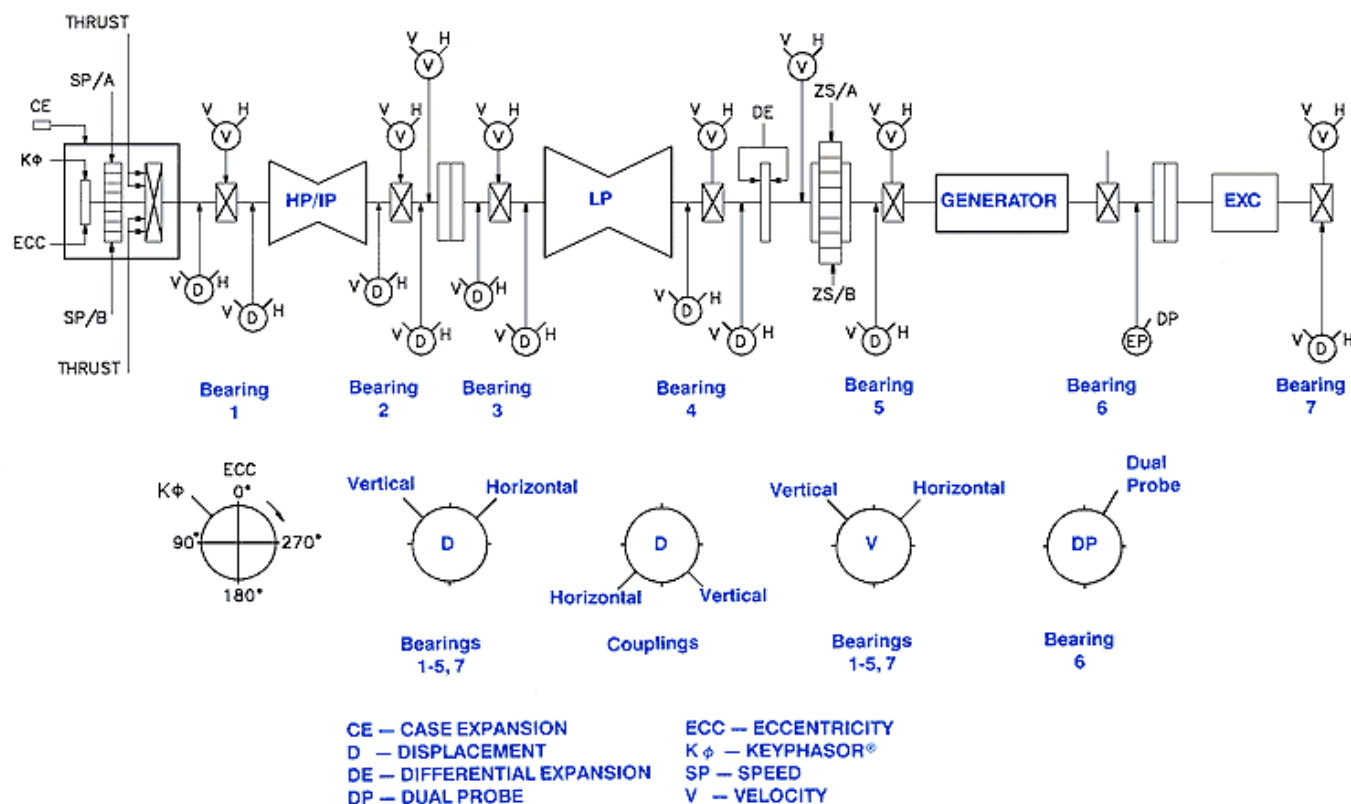


Figure 1  
North Valmy Unit 1 machine train configuration



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Sierra Pacific Power Company's North Valmy Station maintains and operates two turbogenerator sets. Unit #1 is a Westinghouse 254 MW steam driven, seven bearing turbine/generator set. Originally, Turbine Supervisory Instrumentation (TSI) Systems monitored both the main turbine and boiler feed pump. The system interfaced with external chart recorders, a special annunciator panel and the main Westinghouse control computer. Many of the original monitors incorporated a variety of modifications specified by Westinghouse to accommodate specific needs for transducer input, recorder output and relay circuits.

Most TSI systems are quite similar and monitor hardware for rotor lateral vibration, thrust, eccentricity, case expansion, differential expansion, speed, zero speed, and valve position. Variations in the number of points being monitored or the specific type of monitor being used may exist from system to system, however.

The first phase of the project was completed during a recent major turbine outage. This involved installing sets of shaft-observing XY displacement transducers along the machine train (Figure 1). Vibration data was captured from sets of orthogonal displacement probes placed inboard and outboard of all turbine bearings and adjacent to couplings. Since this case history was written, additional pairs of displacement probes have been installed across the generator and exciter bearings. Casing motion is monitored independently by velocity transducers at all bearing locations. Machinery monitoring is based on the shaft-observing XY relative displacement probes.

The additional probes help provide information necessary to verify synchronous mode shapes over different operating speed ranges. These transducers are therefore called "Mode Identification Probes." Data obtained under normal operating conditions provides a basis of comparison to diagnose possible machine malfunctions. Conventional formats of data presentation and analysis, in terms of Bode, Polar and Cascade plots, yield information on machine operational characteristics.

During the second phase of the project, two complete TSI systems were installed, one to replace the existing 7200 TSI System and one dedicated to research purposes. This was done to provide a stand-alone data acquisition system, enabling research to be conducted without disrupting or compromising the integrity of SPPC's permanent monitoring system.

The intent was to duplicate the existing system's functional properties without special modifications, while providing data acquisition and trending capabilities. Each new system consists of **standard** 3300 Monitors and a Transient Data Manager (TDM). The operations TSI System also includes a Process Data Manager (PDM). PDM will accept turbine/generator related process variables other than vibration, such as lube oil pressure, steam pressures, megawatts, vars, etc. Many such variables are available in either 4-20 mA or 1-5 Vdc outputs. Both outputs are directly compatible with PDM. Bearing, as well as many process-related temperatures, i.e. steam temperatures, are very important and are therefore part of the characteristic database.

The original annunciator panel has been replaced by the TDM computer system located directly at the front of the control room. Acting as a computerized annunciator panel, TDM provides the necessary information for operator control. All displayed monitor information is available from the computer CRT. In addition, operators have immediate access to diagnostic information.

Over the past 18 months, trend data has been continuously archived, while transient data from both scheduled and unscheduled shutdowns has been captured. To date, the large volumes of data have formed a strong behavioral characterization of the unit that has proven quite beneficial to SPPC.

During the early stages of trending, rapid vibration changes from bearing #1 became apparent. Vibration levels did not exceed alarm setpoints; therefore, amplitude changes went essentially unnoticed. In fact, the amplitude typically demonstrated under normal operating conditions was greater than that experienced periodically. The amplitude of vibration wasn't as significant as the fact that changes occurred.

Pronounced changes in direct (unfiltered) vibration were noticed first. Normal running speed amplitudes over load are typically about 3.2 mils (81  $\mu\text{m}$ ) peak-to-peak. Changes in amplitude are quite consistent, down to about 1.8 mils (46  $\mu\text{m}$ ) peak-to-peak (Figure 2). The filtered 1X amplitude and phase also showed significant changes (Figure 3).

Initially, operators could not explain the changes as nothing unusual had occurred during operation. Records indicated changes in load occurred daily without any significant change in vibration on bearing #1.

1X vibration is typically associated with rotor unbalance, which can be caused by a number of mechanisms such as blade erosion, material deposition, a loose rotating part, or thermal bows initiated by rotor-to-stator rub. However, such changes would not be expected to manifest themselves in the fashion demonstrated in this case.

As these possibilities were considered highly unlikely, a practical cause had to be determined. Closer review of operator records indicated that the vibration change occurred during valve testing. Normal operating procedures call for periodic steam inlet valve tests. This test requires operators to leave a "sequential valve" mode and enter a "single valve" mode. Steam flow required for a given load (generator output) is controlled through a group of six governor valves opened by the main control computer in a predetermined sequence. In single valve mode, steam flow is controlled with governor valves opening in parallel. In either case, load can be maintained or changed. Normal operation is conducted in the sequential valve mode where throttling losses are minimized.

To identify why bearing #1 shaft vibration was affected by this change in operation, the mechanism by which steam flow enters the steam chest had to be considered. In sequential valve mode, steam flow initiates from beneath the rotor, introducing a somewhat asymmetric flow condition. In single valve mode, steam flow initiates over a full 360 degrees. The high pressure rotor is affected by this mechanism as is indicated by the vertical transducer DC gap voltage change (Figure 4), which also corresponds to changes in vibration. This explains the change in 1X vibration amplitude and phase. The DC gap change indicates a change of static rotor position within the bearing and subsequently a change in dynamic stiffness. Rotor response, controlled by dynamic stiffness properties, can be very sensitive to this type of change.

In this instance, the system's normal 1X vibration level of 2.6 mils (66  $\mu\text{m}$ ) peak-to-peak is acceptable. However, there are many disadvantages associated with this high vibration and the effects are sometimes only apparent later. The rotor and bearing are experiencing stress unnecessarily, and energy is being dissipated in the form of vibration. Attempts to balance would probably prove frustrating, producing little improvement, and would not justify the associated costs. Governor valve resequencing tests to minimize vibration under normal operating conditions are being pursued. ▶

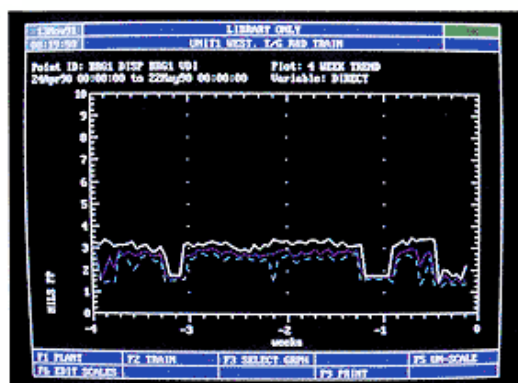


Figure 2  
Trend data indicating rapid changes of bearing 1 vertical transducer unfiltered vibration.



Figure 3  
Trend data indicating rapid changes of bearing 1 vertical transducer 1X filtered vibration amplitude and phase.

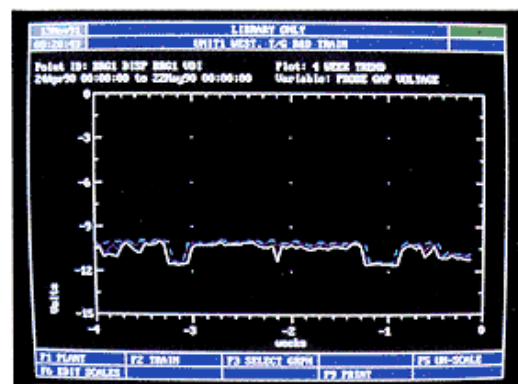


Figure 4  
Trend data indicating rapid changes of bearing 1 vertical transducer gap voltage.



## Case History #2

After a planned shutdown to repair a leaking gasket, operators were concerned when the #7 bearing went into alarm during startup. Although some differences are expected between startups and shutdowns, this particular case was extreme. The unit managed to reach running speed and vibration returned to normal levels. With the unit again running and no explanation for the alarm, further investigation was necessary. Inspection and comparison of shutdown and startup data proved quite interesting. Significant 1X amplitude and phase differences existed over a well-defined and limited speed range. The mechanism responsible for this change was the greatest concern, however. Figures 5 and 6 clearly show a step change in the vibration. Questions were subsequently asked about the history of the unit.

Months prior to the installation of the new 3300/TDM TSI system, a switch flashed over, burning a line support structure. The line fell and subsequently grounded, causing a severe phase imbalance in the generator. Operators managed to keep the unit from tripping off-line, while maintenance crews quickly repaired the switch and line support structure.

The next day, the unit was intentionally shut down to repair a sticking intercept valve. After restarting the unit, operators noticed excessive generator vibration and subsequently brought the unit back down. The unit was placed on turning

gear for further investigation. Records indicated that, within a two minute period after the switch flashed, generator voltage went from 22.5 kV to 19.9 kV, megavars reached 200 out, while exciter voltage reached 150 Vdc. The generator rotor had developed a severe bow, thermally induced by the phase imbalance. After remaining on turning gear for approximately 48 hours, the bow was sufficiently reduced and the unit was placed back into operation.

In this case, further review of data, such as DC gap, was inconclusive. Therefore, generator-related tests were conducted to further investigate possible causes of the 1X vibration step change. A parametric approach was taken to help isolate possible causes. Tests included rapid load changes, extreme var swings, a 150 MW rejection resulting in a trip, and a restart resulting in a mechanical overspeed trip.

Load and var tests showed no unusual behavior and proved inconclusive. Electrically, the system performed quite well. Shorted windings were initially suspected; however, no indication of this malfunction was apparent. Comparison of transient startup and shutdown data taken during the unit trip and restart proved quite interesting, (Figures 5 and 6). Significant amplitude and phase differences existed over a well-defined and limited speed range.

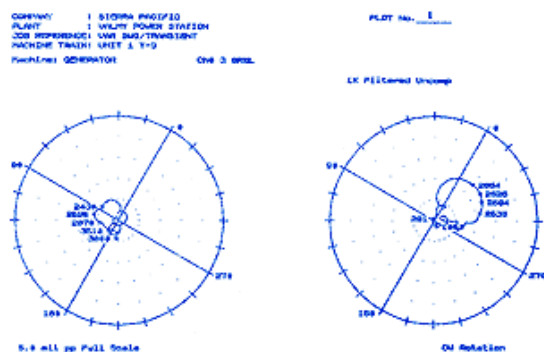


Figure 5

1X Polar plots comparing bearing 6 vertical transducer response during shutdown following a 150 MW trip (left) and subsequent immediate restart (right).

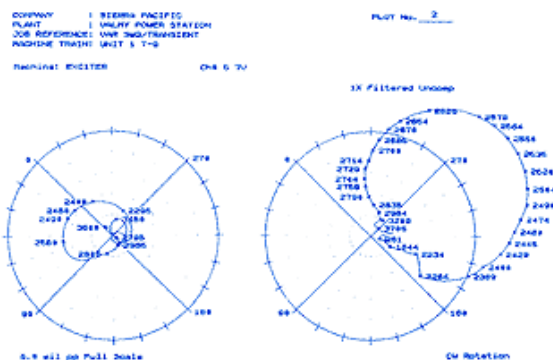


Figure 6

1X Polar plots comparing bearing 7 vertical transducer response during shutdown following a 150 MW trip (left) and subsequent immediate restart (right).

The step change in vibration only occurred while rotor speeds were increasing and then only after the unit had previously slowed to turning gear speed. With the unit running, no unusual mechanical effects were observed.

The question became, "Does the condition of the generator warrant major inspection at this time?" Based on similar cases, the most likely cause was that the switch flash and subsequent severe thermal bow caused a wedge to loosen in the generator. This wedge physically shifted as centrifugal forces increased with rotor speed, thus changing the rotor unbalance. Although there have been cases where generators experienced broken and/or moving retaining rings, the highly consistent, repeatable changes in vibration would not be expected. Electrically the generator appeared normal; mechanically the system was quite predictable.

The generator/exciter was visually inspected while in place during a scheduled maintenance outage. This inspection, however, was extremely restricted due to limited access. An abnormally high amount of dusting was found within the generator. An additional bore scope inspection has been scheduled. The following year had previously been scheduled as a "generator major outage." The rotor will be removed for maintenance at that time. This will allow time for appropriate planning and preparation for repairs from both a system as well as budgetary standpoint.

A decision was made to continue normal operation on the presumption that step changes in vibration were initiated by a loose wedge. With the 3300/TDM System in place, any significant subsequent changes will become immediately apparent.

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## **The future of on-line vibration monitoring systems: Expert Systems, the next logical step**

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As computer-based monitoring and diagnostic systems continue to advance, so has the need for efficient analysis and correlation of the vast amounts of data being stored. Computers can accomplish such tasks very quickly, providing valuable assistance to operators and engineers.

The use of expert systems in rotating machinery analysis can provide a way to apply knowledge acquired during normal and abnormal machinery operation. However, data merely captured and displayed does not spread knowledge. The form of the data must be interpreted. This is what makes the machinery specialist's role significant. The expert system does not replace the machinery specialist, but enhances the effective use of information, thereby promoting safe and efficient operation of complex systems.

There are significant differences between fundamental approaches to expert systems. Typically, an expert system requires relatively large amounts of information in order to begin a meaningful analysis. Ideally, machine information is acquired from a database and is captured and archived during actual operating conditions. This database could include machine vibration, process variables, and any reference data or pertinent historical information.

Decision processes and conclusions are based on actual machinery information compared to requiring a user to answer a continuous list of questions, which may unknowingly require premature speculation. By interrogating a database, the computer essentially answers its own questions. Rule sets are based on a combination of the computer's ability to evaluate the form of the data and on analytical models. This process is highly efficient and does not rely on the user's ability to answer questions or interpret information accurately. The decision-making process should be available to the user. This not only provides a sense of confidence, but now the system becomes a powerful educational tool.

### **Conclusions:**

Vibration monitoring systems are more sophisticated, not only in system hardware but with applications of the information being captured. It has been demonstrated that vibration is a secondary characteristic of rotating machinery behavior, existing as a result of an underlying cause.

The use of 3300/TDM Systems at the Valmy Generating Station has provided Sierra Pacific Power Company with modern monitoring capabilities and associated operating benefits. In addition, data is available for research applications including further development of Observed Synchronous Dynamic Stiffness concepts and engineering assist, expert-type systems, capable of converting data into meaningful information. Properly executed, these systems can be powerful and effective educational tools.

Through advanced monitoring and analysis on Valmy Unit 1, Sierra Pacific Power Company enjoys increased availability, reduced maintenance costs and improved outage scheduling. Research concepts and methodology can be applied, and new products can be tested under actual field conditions. Data that is not available in a laboratory environment can be measured and recorded, while obtaining direct user feedback.

The outcome of such a cooperative effort between the power generation and vibration research industries is an improved understanding of machine behavior, resulting in more efficient operation, advanced analytical methodology, and the availability of monitoring systems that meet users' needs. ■